HIGHWAY RESEARCH REPORT

EVALUATION OF PROTECTIVE COATINGS FOR CORRUGATED METAL PIPE

FINAL REPORT

73-05

March, 1973

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

CA-HY-MR-6655-1-73-05

STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

March 1973
Final Report
M&R No. 646655

Mr. George A. Hill
Assistant State Highway Engineer
Engineering Services
California Division of Highways

Dear Sir:

Submitted for your consideration is a research report titled:

AN EVALUATION OF PROTECTIVE COATINGS

FOR CORRUGATED METAL PIPE

Principal Investigator

J. R. Stoker

Project Engineer and Report By

John P. Dusel, Jr.

Under the Supervision of

Eric F. Nordlin

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE AN EVALUATION OF PROTECTIVE COATINGS FOR CORRUGATED METAL PIPE		5. REPORT DATE March 1973 6. PERFORMING ORGANIZATION CODE 19601-762504-646655
7. AUTHOR(S) Nordlin, E. F., Stoker, J. R. and Dusel, J. P. Jr.		8. PERFORMING ORGANIZATION REPORT NO. CA-HY-MR-6655-1-73-05
9. PERFORMING ORGANIZATION NAME AND ADDRESS Materials and Research Department California Division of Highways Sacramento, California 95819		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS California Division of Highways Sacramento, California 95807		13. TYPE OF REPORT & PERIOD COVERED Final Report 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Procedures and results of tests performed on corrugated culvert pipe protective coatings are reported. Four different protective coatings, Nexon, Copoly-X (Terrashield and Raceway), Pioneer Culvert Mastic #1008, and asphalt, were evaluated by appropriate laboratory tests such as abrasion tests, plate bending tests, ring deflection tests, and salt spray (fog) tests.

Abrasion tests gave a good indication of relative wear resistances for the various coatings. Plate specimens were bolted inside a 24 inch diameter sealed drum and were tumbled with charges of aggregate and water. Thickness measurements were made before and after testing. Percent wear and average coating thickness losses were calculated. Nexon was found to abrade the least, followed by asphalt and Pioneer Culvert Mastic. Copoly-X Raceway and P.C.C. mortar-lined pipe specimens were also abraded and compared. Raceway was found to outwear pipe mortar.

Plate bending tests were performed by bending 2" x 6" plate specimens around a 1 inch diameter mandrel. Results showed that all specimens, with the exception of Copoly-X Terrashield which developed cracks, could be bent easily to a 90° angle without damage.

(Continued)

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Abrasion resistant coatings abrasion test, bend tests, coatings, corrosion, corrugated metal pipe, deflection test, pipe protection, protective coatings, test methods	Unlimited

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	48	

HMRT – 1242 (ORIG. 9/72)

16. Abstract (Continued)

Sections of 18 inch diameter pipe were deflected 5% of the initial diameter in the ring deflection tests. The only specimens which developed cracks were those coated with Copoly-X compounds.

Corrosion experiments were limited to specimens subjected to a minimum of 4400 hours of the ASTM Salt Spray (Fog) Test. Specimens of Nexon and Pioneer Culvert Mastic prevented corrosion at least as well as the asphalt specimens. The Copoly-X Terrashield coating and the yellow 1/2 mil coating on the underside of Nexon specimens did not perform as well as asphalt.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance and expertise given by members of the California Division of Highways, Materials and Research Department, including R. F. Stratfull, C. G. Yeaw, G. K. Oki and others, who contributed to this report.

TABLE OF CONTENTS

I. INTRODUCTION

The investigation of protective coatings for corrugated metal pipe was undertaken to develop a test procedure and to evaluate various corrosion and abrasion resistant coatings for corrugated metal pipe.

Asphalt has been used extensively as a protective coating on corrugated metal pipe. As a result of the recent environmental improvement program, which has imposed stringent restrictions on air pollution, the use of bituminous coatings whose application to corrugated metal pipe requires heating, is becoming less practical. Industries producing corrugated metal pipe are developing new coatings which are economically competitive with asphalt and whose application will reduce environmental pollution.

Four different coatings which were evaluated in this program are as follows:

1. USS Nexon -- a coal tar-based laminate which through heat and pressure is applied to galvanized steel culvert sheets.

2. Pioneer Culvert Mastic #1008 -- a cold applied asphaltic mastic produced by Daubert Chemical Company.

3. Copoly-X -- a two component, chemically reactive, filled coating system consisting of a copolymer and a catalyst developed by Pacific Corrugated Culvert Company and marketed under the nomenclatures of Terrashield and Raceway.

   Terrashield -- a thin coating proposed for use on the exterior of corrugated pipe to protect the pipe from corrosion.

   Raceway -- a heavy invert paving which covers 15% of the pipe periphery and fills the corrugations, proposed for use to protect the pipe invert from abrasion.

4. Hot applied asphalt -- currently the most popular coating used as protection against corrosion and abrasion of culvert pipe.

Four tests were used to evaluate the coatings:

A. Abrasion test.
B. Plate bending test.
C. Ring deflection test.
D. Salt Spray (Fog) test.

All corrugated pipe sections and flat plates used in the following tests were 16 gage galvanized steel complying with the requirements of AASHO Designation: M36. Corrugations in pipe and sheets had a pitch of 2-2/3 inches and a depth of 1/2 inch.

II. SUMMARY

Abrasion tests were conducted using a fine aggregate (minus No. 4) charge for thin corrosion protective coatings and a heavier coarse aggregate (3/8" x 1/2") for abrasion of thick invert paving materials. The use of 3/8" x 1/2" aggregate was chosen as an abrasive charge to evaluate invert paving materials as this size of charge was considered more representative of an abrasive stream bed load. For conditions where a protective coating is required on the interior of a pipe due to a corrosive effluent rather than an abrasive bed load, a finer aggregate was considered more representative, and was used as an abrasive charge for evaluating corrosion protective coatings.

Where the fine aggregate was used, a good indication of corrosion coating wear was achieved when coated corrugated steel plate specimens were allowed to turn in the abrasion drum at 5 fps for approximately 500,000 revolutions. For the invert paving specimens, the same drum speed was employed but only 121,580 revolutions were necessary to determine wear characteristics using the heavier aggregate as an abrasive charge.

Average abrasion thickness losses and percent wear for 500,000 revolutions calculated for the three types of corrosion coating specimens shown in Tables 3 through 6 are as follows: Nexon (.0055" -28.6%), asphalt (.0122" -14.8%) and Pioneer Culvert Mastic (.0207" -32.5%). Percent wear is shown as the applied coating thickness varied for the different materials under evaluation.

Results of the abrasion tests performed on the two invert paving materials shown in Table 7 indicate that after 121,580 revolutions, Copoly-X Raceway coated specimens have an average thickness loss of .031" and 19.2% wear, and portland cement mortar-lined pipe specimens, .086" and 17.4% wear.

Plate bending tests were performed only on the thin corrosion protective coatings of Nexon, asphalt, Pioneer Culvert Mastic, and Copoly-X Terrashield. Specimens, consisting of 2" x 6" coated flat plates, were bent slowly around a one inch diameter mandrel until either cracks were noticed or a 90° angle was reached. Asphalt, Pioneer Culvert Mastic, and Nexon specimens could be bent to 90° without cracking; however, both sets of Copoly-X Terrashield specimens developed cracks at small angles - less than 20°.

Ring deflection tests were performed on all coatings. Corrugated pipe sections, eighteen inches in diameter and twelve inches long coated with various protective materials, were deflected 5 percent of their original diameter. Cracking did not occur on any samples coated with asphalt, Nexon, or Pioneer Culvert Mastic, however, sample coatings of Copoly-X Terrashield and Raceway did crack.

Corrosion experiments were limited to specimens subjected to the salt spray (fog) test. Nexon, asphalt, Pioneer Culvert Mastic, and Copoly-X Terrashield coated specimens were all subjected to a minimum of 4400 hours of salt fog testing.

Asphalt coated corrosion specimens exhibited a loss of adhesion between the asphalt coating and the flat or corrugated galvanized steel plate, but little visible corrosion was present. Nexon and Pioneer Mastic specimens were noted for their exceptionally good bond qualities and from the tests performed are expected to perform at least as well as asphalt in preventing corrosion. The 1/2 mil paint type coating on the opposite side of Nexon specimens, which had allowed extensive visible corrosion to occur, and the Copoly-X Terrashield coating which had also permitted significant corrosion, are not expected to protect corrugated metal pipe as effectively as asphalt.

III. CONCLUSIONS AND RECOMMENDATIONS

A series of tests performed on the various coatings in this program provides a reasonable means of evaluating the over-all performance of a new culvert coating material. The abrasion test developed during the course of this project seems to give a good indication of the relative wear resistance of the coating tested, and the aggregate size can be varied to achieve the desired wear rate depending on the coating type and thickness. Based on the abrasion testing conducted in this research program, a coal tar-based laminate produced by U. S. Steel Corporation and called Nexon showed the best wear resistance. The wear resistance of hot applied asphalt was the next to best of the coatings tested followed by a cold applied asphaltic emulsion produced by Daubert Chemical Company and called Pioneer Culvert Mastic. The Nexon coating abraded uniformly and lost considerably less material in the abrasion tests than the other coatings. The percent wear, based on the ratio of coating thickness loss to the original coating thickness, was slightly higher than for the asphalt as the applied coating was considerably thinner. The asphaltic materials did not wear as uniformly and tended to cold flow under the action of the abrasive charge resulting in thick and thin spots remaining in the coating upon conclusion of the abrasion tests. The Pioneer Culvert Mastic tested produced only about one-half the resistance to abrasion as the hot applied asphalt.

The plate bending tests and the ring deflection tests were effective in determining the brittleness, bond, and flexibility of a coating. All coated specimens could be bent easily and deflected without cracking with the exception of the Copoly-X specimens.

The Salt Spray (Fog) Test, outlined in ASTM B117, has already been established as a test to evaluate corrosion resistance of numerous materials. All specimens were subjected to a minimum of 4400 hours in the fog chamber. From the results of the Salt Spray (Fog) Test, Nexon and Pioneer Culvert Mastic are expected to perform at least as well as asphalt in preventing corrosion. Due to the significant corrosion which was present on specimens coated with Copoly-X Terrashield and on the opposite side of Nexon coated specimens, neither the Terrashield coating nor the 1/2 mil yellow corrosion-resistant coating applied to the opposite side of Nexon coated specimens can be expected to inhibit corrosion as well as asphalt. In special cases it may be desirable to thoroughly evaluate effects from additional chemicals known to be present in discharge water by conducting additional tests.

Based on the results of the tests performed on the various coatings evaluated in this program, Nexon was found to be an acceptable material for use as a protective coating for corrugated metal pipes as an alternate material to a hot applied asphalt coating. It provides good corrosion protection and adequate abrasion resistance for use inside of pipes where a coating in addition to zinc spelter is required. Its use inside of pipes would be restricted to those areas where highly abrasive conditions do not exist without further testing to define its ultimate abrasion resistance. The 1/2 mil yellow corrosion resistant paint used on the opposite side of Nexon coated pipes was found not to equal the corrosion protection offered by asphalt and should be used only when there is little or no corrosion expected to occur on the pipe exterior.

A cold applied asphaltic mastic known as Pioneer Culvert Mastic is considered an acceptable coating to protect the exterior of corrugated metal pipes from corrosion. It is recommended that it be allowed as an acceptable alternate material to hot applied asphalt in equal thickness for all applications where metal is required to be coated to protect it from corrosion. This mastic, however, is not considered equivalent to asphalt to protect the interior of pipes unless abrasion is not a factor in material selection.

Neither of the Copoly-X materials tested in this program - Terrashield and Raceway - is considered acceptable material where its function is to protect against corrosion. The Raceway material was found to possess excellent abrasion resistance and would be an acceptable invert paving material where interior pipe corrosion would not be a consideration or if cracks that formed in the material or at the interface of the paving and the pipe from handling or construction could be adequately sealed. It may also be an acceptable invert paving material if placed after completion of pipe installation to preclude cracking.

Through this research project, the evaluation tests used were found to be excellent tools to investigate new protective coatings and should be adapted as standard tests.

The evaluation of wear characteristics and corrosion protection and comparisons of the various protective coatings made from results of laboratory tests presented in this report need to be verified by actual performance records before any definite service life or field performance can be determined. On the basis of the work reported herein, it is recommended that a standard laboratory test method be prepared so that any further new coatings might be evaluated for use in the same manner.

IV. TEST PROCEDURES AND TECHNICAL DISCUSSION

A. Abrasion Test:

In the case of Nexon, Copoly-X (Terrashield and Raceway), and asphalt coated test specimens, sample preparation involved cutting plates of the shape shown in Figure 1 with a band saw from 18 inch diameter helically corrugated and coated pipe samples received from manufacturers. Pioneer Culvert Mastic #1008 was applied in the laboratory by brush to clean galvanized corrugated pipe specimens as near to a .060 inch minimum thickness as possible. Specimen thicknesses of the various materials were measured with a micrometer. Coating thicknesses were calculated from the total specimen thicknesses and were based on a 16 gage galvanized corrugated steel sheet thickness of .0635 inches. Coating thicknesses of specimens were found to have the following ranges:

Nexon = .016" to .024" (supposed to be .020")

Pioneer Culvert Mastic = .035" to .113"

Copoly-X (Terrashield) = .027" to .064"
(Raceway) = .150" to .182"

Asphalt = .043" to .089"

Manufacturers of various coatings specified that coating thicknesses should be within the following limits:

Nexon = From .010" to .020" ± .001"

Pioneer Culvert Mastic = .060" (minimum)

Copoly-X (Terrashield) = .020" ± .005"
(Raceway) = .125" ± .010"

Asphalt = .050" (minimum), AASHO Designation: M190

Abrasion tests were conducted by bolting specimens cut from the wall of helically corrugated metal pipe in a steel drum, 24 inches in diameter and 8 inches wide, shown in Figure 2. The specimens were placed parallel to and in the proximity of the barrel of the drum. The helically corrugated specimens were fastened in the drum in such a manner as to duplicate the orientation of the corrugations to the axis of a pipe in place. Preliminary tests were conducted to determine the type and amount of aggregate to be used as an abrasive, the proper speed of the drum, and the appropriate amount of water to add with the aggregate.

Two initial tests were run. For both tests a charge of 3/8" x 1/2" Fair Oaks river-run aggregate (7 lbs.) and 59 pounds of water were added to the drum. Specimens revolved inside the drum at a peripheral speed of 3.65 fps. This speed approximated that used in Bureau of Reclamation research, specified in Report No. P-93, Erosion Studies of Pipe Lining Material - Third Progress Report of June 1963. The first initial test run with four specimens, one each of asphalt, Nexon, Copoly-X Terrashield, and Pioneer Culvert Mastic #1008, were abraded for 174,312 revolutions, when the asphalt specimen had just begun to fail. Intermediate thickness measurements were made at 49,022 revolutions, when it was observed that the Pioneer Culvert Mastic specimen had already failed due to an insufficient coating thickness. For the second initial test run two additional Pioneer Culvert Mastic specimens were prepared with thicker coatings and were abraded, using the same speed and amounts of water and aggregate, for 103,015 revolutions. It was observed that one of the mastic coated specimens had failed after this period of abrasion.

All coating thicknesses of specimens were measured at appropriate times during both initial abrasion tests. Thickness measurements were made with a micrometer and were taken at 14 different locations on the corrugated plate specimen as shown in Figure 1.

The initial number of specimens tested was very limited but results indicated that the test method was realistic and practical. One shortcoming of the initial method of testing was observed. Due to the large size of aggregate used as an abrasive agent, it was noted that the hard Copoly-X Terrashield material tended to chip rather than wear smoothly, and the softer asphalt and Pioneer Culvert Mastic specimens were being kneaded rather than abraded. As this action would not be expected to occur in field installations when abrasive conditions are such that a paved invert would not be required, a decision was made to conduct further tests using an aggregate charge consisting of a typical portland cement concrete sand to measure the abrasion resistance of the thin corrosion protection coatings.

Results from initial tests indicate that the abrasion resistance of the four corrosion protection coatings follow a definite pattern: (1) Nexon wears best, followed by (2) asphalt, (3) Copoly-X Terrashield and finally (4) the Pioneer Culvert Mastic #1008.

Tables 1 and 2 show the coating thicknesses at various points during initial abrasion tests using the 3/8" x 1/2" abrasive charge. After the completion of initial tests, Pacific Corrugated Culvert Company discontinued marketing Copoly-X Terrashield as a protective coating to be used on the inside of corrugated metal pipes. Hence, no Copoly-X Terrashield coated specimens were used in later abrasion tests with concrete sand following the initial test runs shown in Tables 1 and 2.

Five additional abrasion test runs were performed so that the loss of coating thickness could be determined more accurately and a more representative abrasive charge could be used as explained previously. One specimen of asphalt, Nexon, and Pioneer Mastic were abraded in each of the first three additional test runs. Four specimens of Pioneer Mastic were used in the fourth additional test. These four test runs were conducted using 7 lbs. of minus No. 4 Bear River fine aggregate, and 35 pounds of water. The gradation of the sand complied with the requirements of Section 90-3.03, Fine Aggregate Grading, of the 1972 Standard Specifications.

Pulleys on the drum and motor were adjusted to provide a peripheral speed of 5 fps at the surface of the test specimens for these last five test runs.

Thickness measurements were again made with a micrometer, but were taken at 12 different locations and only on the wear surfaces. Figure 3 shows positions of micrometer readings for additional tests 1 through 4.

Results of these tests are shown in Tables 3, 4, 5, and 6. The relative abrasion resistance was noted with Nexon wearing best, followed by asphalt, then Pioneer Culvert Mastic.

A fifth additional abrasion test was run to compare Copoly-X Raceway to portland cement mortar-lined corrugated metal pipe. Mortar-lined pipe specimens were prepared by painting corrugated steel plates with an epoxy used for bonding fresh concrete and then troweling pipe lining mortar onto the plates. The mortar was made using a 2-1/2:1 sand-cement ratio. The mix contained 5675 grams of sand, 2270 grams of Type II modified cement and 750 ml of water. The sand used was a No. 4 maximum, well graded, Fair Oaks sand conforming to Bureau of Reclamation mortar sand grading limits. The mortar-lined pipe specimens were fog cured for 7 days prior to testing.

A 7 pound charge of 3/8" x 1/2" Bear River river-run aggregate and 35 pounds of water were added to the drum containing 2 specimens of both Raceway and mortar-lined pipe. The four locations where thickness measurements were taken are shown in Figure 4. Measurements were made before and after the test. The Raceway material seemed to abrade slower than the mortar-lined pipe. Table 7 shows wear characteristics of the specimens. It should be recognized, however, that the abrasion resistance of portland cement concrete improves with age or strength gain, thus the comparison shown may not be as favorable with well cured mortar specimens.

A.1 Summary of Abrasion Test Results

From the abrasion tests conducted, it was evident that Nexon had by far the best wear resistance of all specimens tested. It wears slowly whether a coarse aggregate or a fine aggregate is used as an abrasive material. The very little extra weight which the Nexon coating adds to the pipe, a smooth, clean surface, and a uniform coating thickness are factors which make this material very desirable for handling and use.

The asphalt coating did a satisfactory job as an abrasion protector when a fine aggregate was used as an abrasive; however, a coarse aggregate seemed to knead the asphalt, causing it to ripple and flow on the heavily impacted corrugated surface. This kneading of the asphalt coating is believed to contribute to failure of the coating and exposure of the zinc coated metal. Asphalt specimens were generally messy to handle and cut, the coating added considerable weight to the pipe, and the uniformity of the coating thickness left much to be desired.

Of the specimens tested, the mastic produced by Daubert Chemical Company seemed to abrade the quickest, and in all cases failed before the other specimens. As observed in the asphalt specimens, a kneading action took place. This material seems to require at least 3 days to cure, and like asphalt is quite messy to handle and apply. The material is a mastic, and the volatiles which evaporate when the material is drying may prove dangerous if large amounts of the mastic are applied in a confined area. Spreading the mastic to an adequate, even thickness may prove to be difficult. However, with the use of proper equipment and application techniques, this may not prove to be a serious problem.

Average thickness losses for all specimens were calculated from Tables 3, 4, 5, 6, and 7 by taking the one largest thickness loss measurement from each of the four groups of the three consecutive measurement locations (see Figure 3) and summing these four measurements, then dividing by 4 and multiplying the resulting average thickness loss by 500,000 divided by the number of revolutions for that sample. As an example, calculations for the Nexon specimen in Table 3 are shown below:

$$\frac{(.009" + .007" + .007" + .004")}{4} \times \frac{500{,}000}{503{,}763} = .0067",\text{ the}$$

average coating thickness loss per 500,000 revolutions. The abrasion tests were discontinued at about 500,000 revolutions as at this point the coating on the mastic specimens was gone in one or more locations.

From Tables 3, 4, and 5, individual specimen thickness losses, average thickness losses and average percent wear were calculated for the different coatings. For individual asphalt specimens having thickness losses of .0094", .0127", and .0146", the average thickness loss for the three specimens was .0122" and the average percent wear was 14.8. For three Pioneer Culvert Mastic specimens individual thickness losses were .027", .0298", and .0286", the average thickness loss was .0285", and the average percent wear was 57. Individual Nexon specimen thickness losses were .0067", .0037", and .006", and the average thickness loss was .0055" with an average percent wear of 28.6. Above calculations are based on 500,000 revolutions at 5 fps using minus No. 4 aggregate as an abrasive.

From Table 6 Pioneer Culvert Mastic specimens were found to have individual thickness losses of .0103", .0262", .005", and .0105" per 444,778 revolutions. The average thickness loss for these four specimens is .013" and the average percent wear is 17.4.

Individual specimen thickness losses calculated from Table 7 were found to be .101" and .071" for the pipe lining mortar, having an average thickness loss of .086" and a percent wear of 17.4, and .031" and .031" for Copoly-X Raceway specimens, having an average thickness loss of .031" and a percent wear of 19.2. Calculations from Table 7 are based on 121,580 revolutions at 5 fps using 3/8" x 1/2" aggregate as an abrasive charge. The test was arbitrarily discontinued at this point as significant wear of the mortar on the mortar-lined specimens had occurred during this period of time. Any further abrasion would have resulted in loss of the coarse sand in the mortar coating.

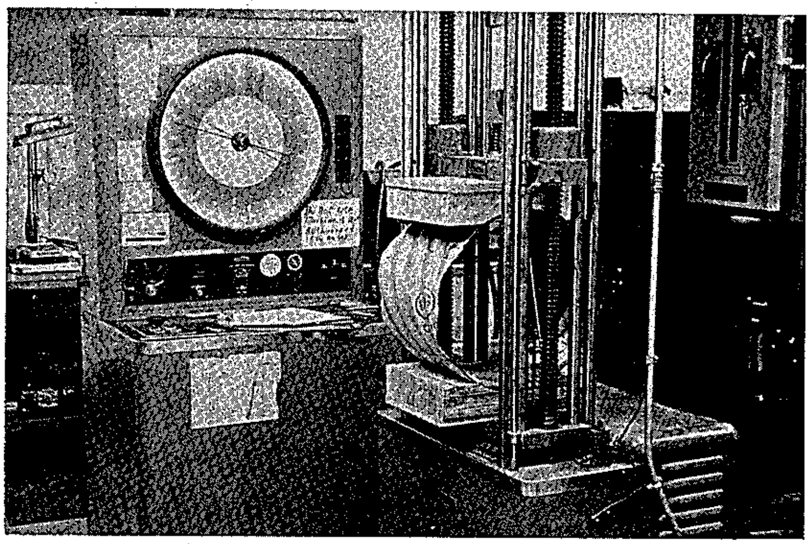
B. <u>Plate Bending Tests</u>

Plate bending tests performed on 2" x 6" flat galvanized sheet stock coated with the four corrosion-protection coating materials are considered good indications of flexibility and bond strength of the coating. Specimens were tested by clamping one end of a plate in a vise and bending the plate around to 1 inch diameter mandrel. Specimens were slowly bent as far as possible until either cracks appeared or a 90° bend was achieved. Specimens of asphalt, Pioneer Culvert Mastic, and Nexon all could be bent easily to 90°. Six initial specimens of Copoly-X Terrashield with an average coating thickness of .033 inches developed cracks after plates were bent between a 6° and 9° angle. Additional modified Terrashield specimens were received and tested. The average coating thickness of additional specimens was .018 inches. These specimens developed cracks between a bend angle of 15° and 19°. This indicates that with a thicker coating, cracking would occur at a bend angle of less than 15°. This brittleness may be undesirable for a coating for a flexible pipe.

C. Ring Deflection Test

Ring deflection tests were conducted on cylindrical sections of coated or paved pipe 12 inches long and 18 inches in diameter. The pipe was helically corrugated. The purpose of these tests was to determine if the coatings had sufficient flexibility to accommodate deflections of pipe due to backfilling operations, ellipsing during fabrication, and various dead or live loads imposed on the pipe without any cracking or bond failure of the coating. A deflection of 5% was chosen as corrugated metal pipes can take this amount of deflection without jeopardizing the structural integrity of the conduit and may receive this amount of deflection in service. Thus it is felt that any coating system should be capable of taking this amount of deflection without any evidence of cracking or delamination of the coating from the pipe.

Two wooden forms were constructed to conform to the curvature of the pipe, so that loads could be evenly distributed over the length of the pipe. The apparatus is shown below.



RING DEFLECTION TEST APPARATUS

A dial gage was used to measure vertical deflections. Calipers were used to measure horizontal deflections. Samples were deflected 5% of the inside diameter by vertical loading in a testing machine. A load was applied and the behavior of the coating was observed under bending stress at .1 inch vertical deflection intervals. As expected, samples coated with Nexon, asphalt, and Pioneer Culvert Mastic showed no signs of cracking or delamination from the metal. Results from a number of tests conducted on pipe coated with Copoly-X Terrashield and Raceway are discussed below:

Four preliminary samples coated with Terrashield and/or paved with Raceway were tested. The first sample tested was coated on the inside and outside of the pipe with Terrashield. The invert was paved with Raceway.

Initial separation between the Raceway and pipe (small cracks about .010 inches in width) was noticed along the Raceway edges during the ring deflection tests. From 0 to .3 inches vertical deflection, no apparent changes took place. At .4 inches deflection, further separation of the Raceway from the pipe was observed. No other cracks were noticed on the outside or inside coating. At .5 inches deflection, cracking and separation along the Raceway border continued. No other visible cracks were present. At .6 inches deflection hairline cracks in the valleys of outside corrugations at mid-length of the pipe specimen and along the pipe sides had begun. Raceway cracking continued. At .7 inches deflection, the small cracks on the outside of the pipe had lengthened slightly. At .8 inches deflection, the small hairline cracks on the outside of the pipe (in valleys of corrugations) had increased in numbers. More cracks were apparent on one side than on the other. The thick Raceway coating had a fine crack down the center and along one corner through the entire thickness. At .9 inches deflection, more small cracks were noted on the sides with the condition of the Raceway being about the same.

After completing the deflection test, the first sample was removed from the machine and dropped onto an asphalt surface from a five foot height. The Raceway coating in the invert separated completely from the pipe section and broke into 3 pieces, indicating a weak bond between the Raceway primer and zinc coating.

The second sample tested was paved in the invert only with Raceway. Before testing, two fine cracks were present along the seam of the Raceway and pipe. When a vertical deflection of .3 inches was reached, these cracks had widened slightly. At .5 inches the width of the cracks had increased to approximately 1/8 of an inch. From a vertical deflection of .5 inches to .9 inches, the crack widths grew to approximately 3/16 of an inch.

The third sample was coated with Terrashield on the outside of the pipe only. With a vertical deflection of .4 inches, small cracks were noticed in the valleys of the corrugations on the outside of the pipe at the spring line. At .5 inches deflection, the cracks, about .003 inches wide in the corrugation valleys, lengthened slightly. The crack widths increased to .005 inches at .6 inches vertical deflection. At .7 inches vertical deflection, cracks widened to about .010 inches and remained constant to .9 inches deflection.

The fourth sample was coated with Terrashield only on the inside of the pipe. No major failures of coating were noticed while loading the sample. At .8 inches deflection, a small crack along the invert was noticed. The crack did not appear to grow as the deflection increased to .9 inches. The width of the crack was about .003 inches.

After completing ring deflection tests on the first four samples of the Terrashield and Raceway material, Pacific Corrugated Culvert Company manufactured nine new samples and these were submitted for further ring deflection tests. The nine additional ring deflection tests revealed that cracking was still a problem with their material.

Three samples of the nine were coated on the outside only with Terrashield. When these first three samples were tested, the Terrashield coating showed hairline cracks in the valleys of the corrugations on the sides of the samples, similar to those which had appeared on initial samples.

The next three samples tested had Raceway paving in the invert of the pipe only. In all cases small cracks developed along the borders of the Raceway as well as larger cracks developing in the Raceway coating itself.

The last three samples were coated on the outside with Terrashield and had inverts paved with Raceway. Cracks appeared in the valleys of the corrugations on the outside Terrashield coating and also appeared along the edges of the Raceway coating. Very few cracks appeared in the Raceway coating itself.

C.1 Summary of Ring Deflection Tests

Summarizing ring deflection tests, all asphalt, Nexon, and Pioneer Culvert Mastic coatings bent easily, without showing any signs of cracking. Both initial and modified samples of Copoly-X Terrashield and Raceway coatings developed cracks and appeared to be too brittle to be subjected to the wear and abuse received from normal transportation and handling of corrugated metal pipe. The Copoly-X Raceway material may be satisfactory if placed after completion of a pipe installation to preclude cracking.

D. <u>Corrosion Test, Salt Spray (Fog) Test</u>

Galvanized steel specimens protected by each type of coating were subjected to a corrosive environment by placing them in a fog chamber in accordance with the procedures as outlined in ASTM B117, Standard Method of Salt Spray (Fog) Testing.

Specimens coated by each of asphalt, Nexon, and Pioneer Culvert Mastic were subjected to 4511 hours of testing. Copoly-X Terrashield specimens were tested for 4457 hours. All specimens were studied after removal from the fog chamber and the following observations were made:

1. Asphalt:

   Specimens consisted of three flat, rectangular, 6" x 12" plates coated on both sides and edges with asphalt of an average thickness of 0.060 inches. The specimens were asphalt coated by the hot dip process.

   Visible evidence of corrosion was limited to a small band about 1/2 inch wide around the periphery of the specimens. Small white streaks, known as white rust or zinc oxide, were observed on the coating surface along the edges, and indicated that underfilm corrosion had taken place. The asphalt bond to the metal plates was poor on all specimens, and the entire coating could be peeled intact from the metal plates. However, a thin film of asphalt remained on the metal surface after the asphalt layer had been peeled which prevented any visible corrosion, other than the band around the edges of the plates, from occurring.

2. Pioneer Culvert Mastic #1008:

   Specimens consisted of three flat, rectangular, 6" x 12" plates coated on both sides with Pioneer Mastic of an average thickness of 0.063 inches. Two additional 12" x 12" corrugated plates, coated with mastic on one side only, were also tested. Edges of all specimens were protected with Pioneer mastic or a silicone sealer.

   Corrosion similar to that observed along edges of asphalt specimens was present on all plates coated with mastic. Bond was poor along the periphery of all mastic specimens due to some underfilm corrosion. With the exception of visible underfilm corrosion and bond loss which was limited to the specimen edges, the Pioneer mastic had excellent bond to the metal, unlike the asphalt coating which easily peeled from metal plates, and provided good protection to the metal against corrosion. Pioneer Culvert Mastic can be expected to perform at least as well as asphalt in preventing corrosion.

3. Nexon Coating:

Specimens consisted of three 6" x 12" corrugated plates which were cut from a 30 inch diameter culvert pipe with an abrasive disc. One side of each plate was coated with an average thickness of 0.022 inches of Nexon and the opposite side was painted with a 1/2 mil thick corrosion resistant paint coating. The edges of Nexon specimens were not coated.

Zinc oxide or white rust streaking across the Nexon plate surface was extensive because of a lack of edge protection. Edge undercutting corrosion was apparent on all Nexon specimen surfaces due to the lack of edge sealing and was about equal to that of Pioneer mastic specimens, unbonding the Nexon coating within an approximate 3/4" strip along the perimeter of all specimens. With this exception the bond of the Nexon was excellent and the material provided adequate protection to the substrate from corrosion. Extensive underfilm corrosion was evident on the galvanized metal surfaces where the 1/2 mil corrosion resistant paint coating had been applied. The corrosion protection provided by the Nexon coating is at least equal to that of asphalt. However, the corrosion protection offered by the 1/2 mil thick paint coating, which was applied to the exterior surface of the pipe furnished for testing, is expected to be less than that of asphalt.

4. Copoly-X Terrashield Coating:

Specimens of Terrashield included nine flat 6" x 12" plates and three 12" x 12" corrugated plates. Four of the nine flat plates were cross-scratched in accordance with Section 4.4 of ASTM B117 to test for underfilm corrosion. A corrosion resistant paint was applied to the bottom side of all plates with the top side, as viewed in the Salt Spray Chamber, covered with Terrashield.

All specimens were exposed for 4457 hours in the fog chamber. With the exception of four flat plates, small round areas of the Terrashield coating had blistered and separated from the metal plate in numerous places. This bubbling of the Terrashield coating and presence of underfilm corrosion indicates that Terrashield as tested is not equal to asphalt as a corrosion protective coating.

D.1 Summary of Corrosion Tests

Specimens of each type of coating were tested for a minimum of 4400 hours in the fog chamber. Bond failure was present on all asphalt coated specimens, but little visible corrosion was present. All specimens appeared to be most vulnerable to corrosion along edges where the original coating material was not present or where additional coating material applied to edges was perforated. This is not unexpected as it is difficult to seal the edges and this occurrence should not be construed as indicating a deficiency in the coating tested. Nexon and Pioneer Culvert Mastic coatings were found to perform at least as well as the asphalt in preventing corrosion. Substantial corrosion was present on Copoly-X Terrashield coated specimens and also on the opposite side of the Nexon specimens which had been coated with a 1/2 mil of yellow, corrosion-resistant material. These two coatings did not prevent corrosion as well as asphalt.

V. REFERENCES

1. Bureau of Reclamation, Chemical Engineering Laboratory Report No. P-93, "Erosion Studies of Pipe Lining Materials - Third Progress Report", June 1963.

2. Highway Research Board of the National Academy of Sciences - National Research Council, "Field and Laboratory Testing of Aluminum", Highway Research Record Number 95, Publication 1311. January 1965.

3. Curtice, David K., and Funnell, John E., "Comparative Study of Coatings on Corrugated Metal Culvert Pipe", Southwest Research Institute. March 15, 1971.

VI. APPENDIX

TABLES

FIGURES

Location of measurement on specimen	Initial Thickness of Coating, inches: Nexon	Asphalt	Terrashield	Pioneer Mastic	Thickness Change inches, 49,022 revs.: Nexon	Asphalt	Terrashield	Pioneer Mastic	Thickness Change inches, 174,312 revs: Nexon	Asphalt	Terrashield	Percent Wear for 174,312 revs: Nexon	Asphalt	Terrashield
1	.018	.062	.052	.028	+.001	+.019	-.001	failed	+.001	-.001	-.001	-	2%	2%
2	.018	.072	.045	.031	+.001	+.006	-.003		+.004	+.004	-.009	-	-	20%
3	.018	.072	.045	.032	+.001	+.009	-.001		+.002	+.017	-.004	-	-	9%
4	.018	.072	.064	.026	-0-	-.016	-.020		+.001	-.018	-.064	-	25%	100%
5	.015	.077	.057	.034	-0-	-.024	-.004		-.001	-.016	-.003	7%	21%	5%
6	.015	.081	.036	.029	+.004	+.005	+.001		+.005	+.014	+.003	-	-	-
7	.014	.080	.045	.025	+.001	+.002	-.012		-0-	+.027	-.014	0	-	31%
8	.019	.069	.052	.023	+.001	+.006	-.005		-.001	+.013	-.007	5%	-	13%
9	.020	.077	.040	.020	-0-	-.015	-.001		-0-	-.001	-.003	-	1%	8%
10	.019	.081	.042	.025	-.002	-.005	-.005		-0-	+.015	-.005	-	-	12%
11	.017	.070	.056	.027	+.001	-.012	-.019		+.001	+.005	-.056	-	-	100%
12	.015	.081	.028	.019	+.002	-.018	+.009		+.002	-.023	+.005	-	28%	-
13	.015	.080	.027	.029	+.002	+.010	+.003		+.002	+.002	+.003	-	-	-
14	.014	.087	.034	.024	+.005	-.006	-.007	failed	+.002	+.029	-.007	-	-	21%

TABLE 1. INITIAL ABRASION TEST RESULTS

4 specimens, one each of Nexon, asphalt, Copoly-X Terrashield, and Pioneer Culvert Mastic.

Speciman peripheral speed: 3.65 fps
Aggregate charge: 7 lbs. of 3/8" x 1/2" Fair Oaks river-run aggregate
Water charge: 59 lbs.

Location of measurement on specimen	Initial Thickness of Coating, inches Coating Type: Pioneer mastic #1	Initial Thickness of Coating, inches Coating Type: Pioneer mastic #2	Thickness Change - inches, 103,015 revs Coating Type: Pioneer mastic #1	Thickness Change - inches, 103,015 revs Coating Type: Pioneer mastic #2	Percent Wear for 103,015 revs. Coating Type: Pioneer mastic #1	Percent Wear for 103,015 revs. Coating Type: Pioneer mastic #2
1	.137	.022	-.113	failed	83%	100%
2	.061	.049	-.025		41%	
3	.054	.034	-.031		57%	
4	.061	.046	-.052		85%	
5	.105	.069	-.072		69%	
6	.049	.050	+.003		6%	
7	.037	.027	-.037		100%	
8	.138	.037	-.011		80%	
9	.052	.023	-.040		77%	
10	.045	.033	-.035		78%	
11	.035	.049	-.029		83%	
12	.108	.054	-.078		72%	
13	.058	.050	-.020		29%	
14	.048	.027	-.048	failed	100%	100%

TABLE 2. INITIAL ABRASION TEST RESULTS

2 specimens of Pioneer Culvert Mastic

Specimen peripheral speed: 3.65 fps
Aggregate charge: 7 lbs. of 3/8" x 1/2" Fair Oaks river-run aggregate
Water charge: 59 lbs.

Location of measurement on specimen	Initial Thickness of Coating, inches Coating Type			Thickness Change -inches, 503,763 revs. Coating Type			Percent Wear for 503,763 revs Coating Type		
	Nexon	Asphalt	Pioneer Mastic	Nexon	Asphalt	Pioneer Mastic	Nexon	Asphalt	Pioneer Mastic
1	.024	.077	.061	-.009	-.004	+.004	38%	5%	-
2	.024	.070	.061	-.005	+.014	-.025	21%	-	41%
3	.019	.058	.046	-.007	+.025	-.046	37%	-	100%
4	.023	.077	.066	-.005	+.011	+.002	22%	-	-
5	.021	.068	.079	-0-	-0-	-.016	0%	0%	20%
6	.018	.074	.046	-.007	+.001	-.014	39%	-	30%
7	.021	.084	.059	-.005	+.010	-.019	24%	-	32%
8	.020	.080	.051	-.007	-.004	-.008	35%	5%	6%
9	.018	.071	.041	-.005	-.017	-.041	28%	24%	100%
10	.022	.087	.064	-.004	-.017	-.008	18%	20%	12%
11	.021	.088	.063	-.003	-.015	-.002	14%	17%	3%
12	.019	.046	.038	-.004	+.040	-.008	21%	-	21%

TABLE 3. ABRASION TEST RESULTS

3 specimens, one each of Nexon, asphalt, and Pioneer Culvert Mastic

Specimen peripheral speed: 5 fps
Aggregate charge: 7 lbs. of minus No. 4 well graded Bear River fine aggregate
Water charge: 35 lbs.

Location of measurement on specimen	Initial Thickness of Coating, inches Coating Type			Thickness Change -inches, 501,100 revs Coating Type			Percent Wear for 501,100 revs. Coating Type		
	Nexon	Asphalt	Pioneer Mastic	Nexon	Asphalt	Pioneer Mastic	Nexon	Asphalt	Pioneer Mastic
1	.021	.111	.063	-.001	-.014	-.026	5%	13%	41%
2	.020	.102	.073	-.005	+.004	-.037	25%	-	51%
3	.018	.100	.044	-.003	+.001	-.034	17%	-	77%
4	.020	.092	.051	-0-	-.009	-.007	0%	10%	14%
5	.019	.082	.057	+.001	-.014	+.001	-	17%	-
6	.016	.075	.038	-.001	+.003	-.011	6%	-	29%
7	.022	.100	.069	-.004	-.004	-.009	18%	4%	13%
8	.020	.098	.074	-.005	-.007	-.022	25%	7%	30%
9	.015	.097	.042	+.001	-.013	-.032	-	13%	76%
10	.022	.092	.077	-.004	-.002	-.004	18%	2%	5%
11	.019	.075	.073	-.002	-.003	-.017	10%	4%	23%
12	.015	.077	.047	+.001	-.010	-.040	-	13%	85%

TABLE 4. ABRASION TEST RESULTS

3 specimens, one each of Nexon, asphalt, and Pioneer Culvert Mastic

Specimen peripheral speed: 5 fps
Aggregate charge: 7 lbs. of minus No. 4 well graded Bear River fine aggregate
Water charge: 35 lbs.

Location of measurement on specimen	Initial Thickness of Coating, inches Coating Type			Thickness Change inches, 504,269 revs Coating Type			Percent Wear for 504,269 revs. Coating Type		
	Nexon	Asphalt	Pioneer Mastic	Nexon	Asphalt	Pioneer Mastic	Nexon	Asphalt	Pioneer Mastic
1	.023	.074	.048	+.004	-.009	-.014	-	12%	29%
2	.022	.073	.062	-.002	-.012	-.036	9%	16%	58%
3	.019	.073	.043	-.009	-0-	-.043	47%	-0-	100%
4	.022	.072	.054	+.015	-0-	-.005	-	-0-	9%
5	.022	.078	.075	+.002	-.011	-.010	-	14%	13%
6	.016	.086	.040	-.002	-.022	-.017	12%	26%	42%
7	.022	.073	.082	+.009	-.005	-.008	-	7%	10%
8	.018	.075	.092	+.001	-.011	-.030	-	15%	33%
9	.017	.076	.044	-.005	-.012	-.012	29%	16%	27%
10	.022	.081	.077	+.001	-.002	-.015	-	2%	19%
11	.021	.084	.087	-.003	-.003	-.022	14%	4%	25%
12	.019	.085	.054	-.008	-.013	-.025	42%	15%	46%

TABLE 5. ABRASION TEST RESULTS

3 specimens, one each of Nexon, asphalt, and Pioneer Culvert Mastic

Specimen peripheral speed: 5 fps
Aggregate charge: 7 lbs. of minus No. 4 well graded Bear River fine aggregate
Water charge: 35 lbs.

Location of measurement on sample	INITIAL COATING THICKNESS Coating Type - Pioneer Mastic Mastic 1	Mastic 2	Mastic 3	Mastic 4	THICKNESS CHANGE - revs Coating Type - Pioneer Mastic Mastic 1	Mastic 2	Mastic 3	Mastic 4	Per Cent Wear for 400,000 revs. Mastic 1	Mastic 2	Mastic 3	Mastic 4
1	.085	.073	.064	.085	+.007	±.005	+.018	-.001	-	-	-	1%
2	.098	.058	.073	.083	-.016	-.003	+.009	-.019	16%	5%	-	23%
3	.061	.044	.065	.063	+.017	-.044	-.003	-.017	-	100%	46%	27%
4	.085	.064	.056	.078	+.021	+.015	+.003	-.009	-	-	-	12%
5	.073	.060	.064	.081	+.021	+.015	+.003	+.005	-	-	-	-
6	.060	.035	.044	.045	-.013	+.001	-.005	-.002	22%	-	11%	4%
7	.088	.113	.049	.103	+.006	-.006	+.013	-.010	-	5%	-	10%
8	.108	.105	.060	.090	-.008	-.018	+.008	-.005	8%	18%	-	5%
9	.069	.061	.058	.068	+.009	+.017	-.006	-.009	-	-	10%	13%
10	.118	.083	.043	.098	-.004	+.020	+.016	-.004	4%	-	-	4%
11	.081	.063	.065	.080	+.012	-0-	+.006	+.007	-	-0-	-	-
12	.050	.043	.046	.043	+.003	-.043	-.006	-.004	-	100%	13%	11%

TABLE 6. ABRASION TEST RESULTS

4 specimens of Pioneer Culvert Mastic

Specimen peripheral speed: 5 fps
Aggregate charge: 7 lbs. of minus No. 4 well graded Bear River fine aggregate
Water charge: 35 lbs.

Location of measurement on specimen	Initial Coating Thickness, inches Coating Type				Thickness Change, inches 121580 revs. Coating Type				Percent Wear for 121,580 revs. Coating Type			
	Mortar pipe		Raceway		Mortar Pipe		Raceway		Mortar Pipe		Raceway	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
1	.487	.580	.181	.168	-.142	-.100	-.027	-.033	29%	17%	15%	20%
2	.448	.640	.178	.169	-.062	-.087	-.048	-.028	14%	14%	27%	16%
3	.460	.516	.182	.150	-.117	-.060	-.032	-.031	25%	17%	18%	21%
4	.441	.538	.152	.133	-.087	-.039	-.020	-.033	20%	7%	13%	25%

TABLE 7. ABRASION TEST RESULTS

4 specimens, 2 each of Copoly-X Raceway and mortar lined pipe

Specimen peripheral speed: 5 fps
Aggregate charge: 7 lbs. of 3/8" x 1/2" Bear River river-run aggregate
Water charge: 35 lbs.

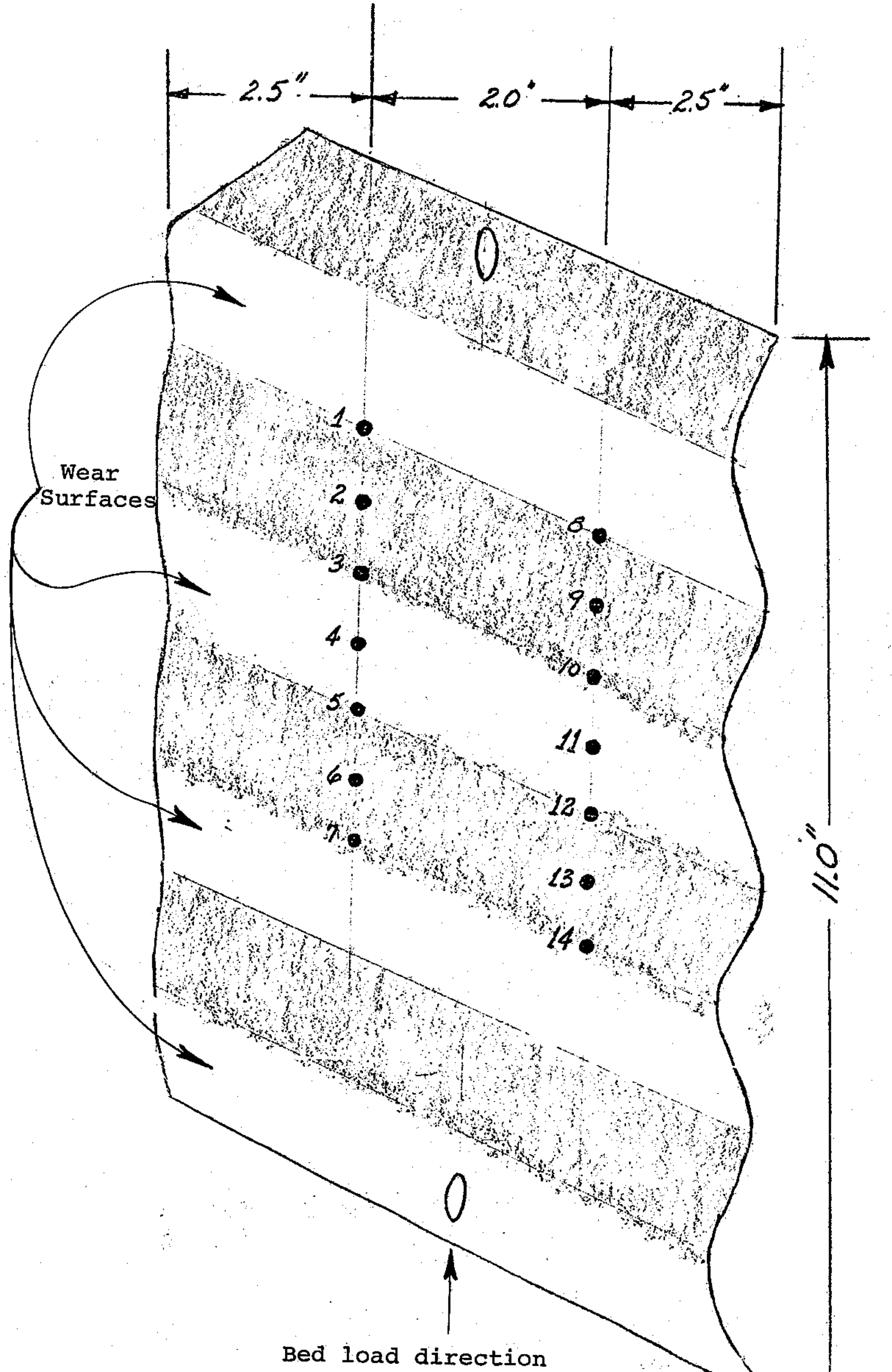


FIGURE 1

Initial abrasion test specimen sizes and thickness measurement locations.

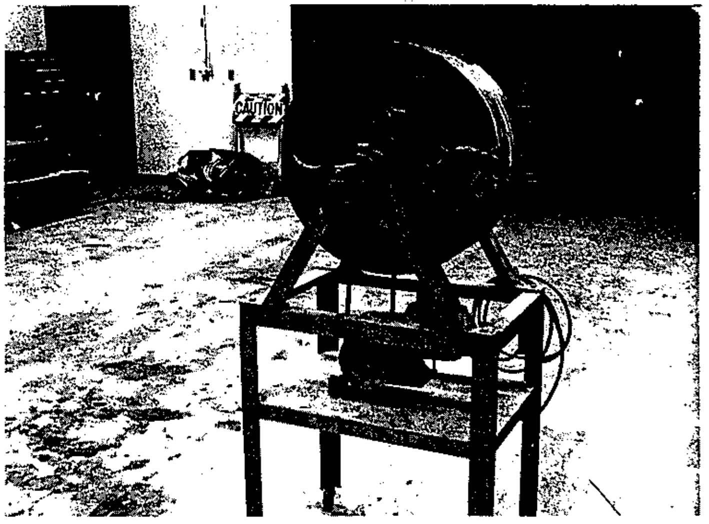


FIGURE 2

Abrasion Testing Machine

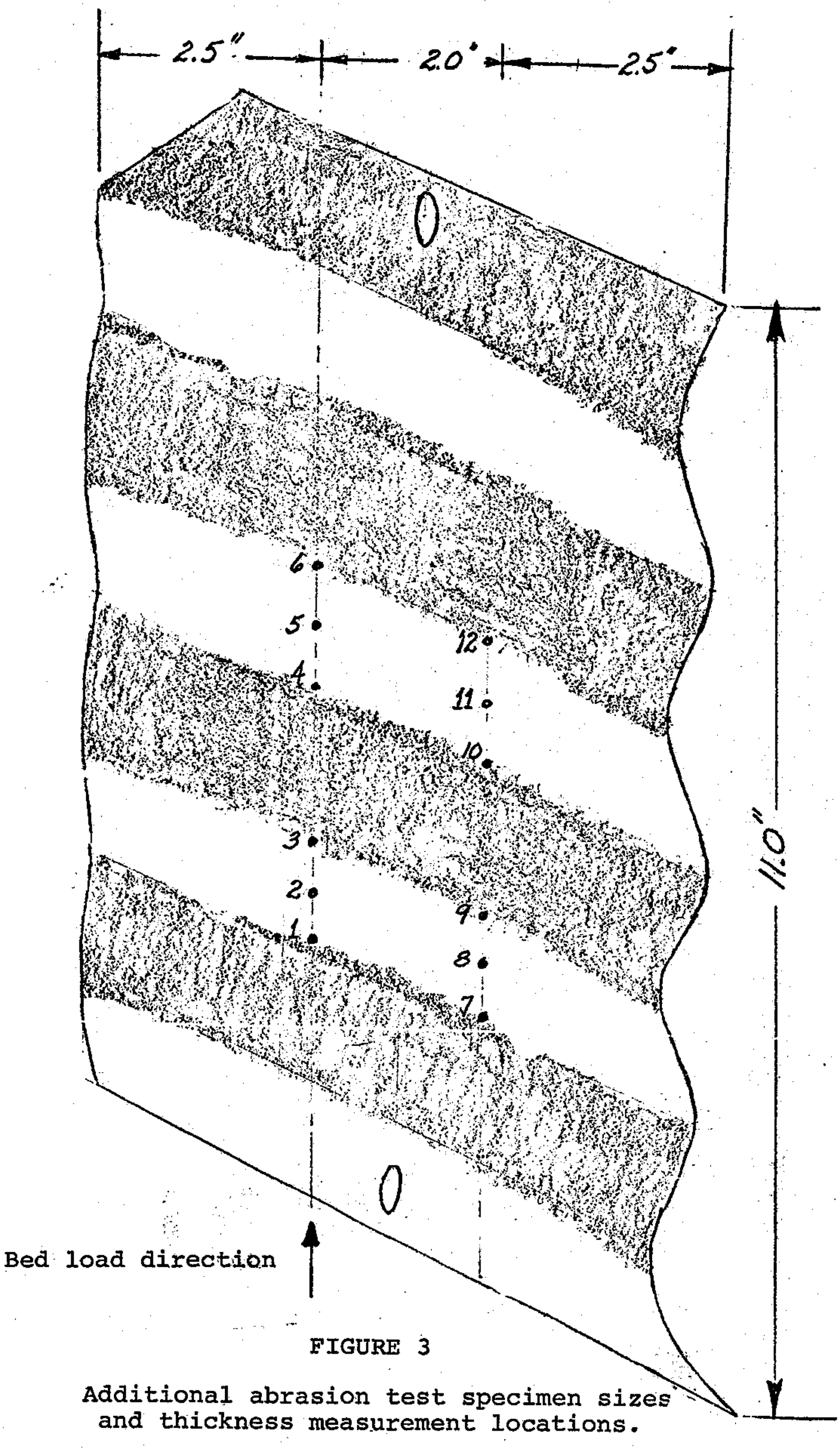


FIGURE 3

Additional abrasion test specimen sizes
and thickness measurement locations.

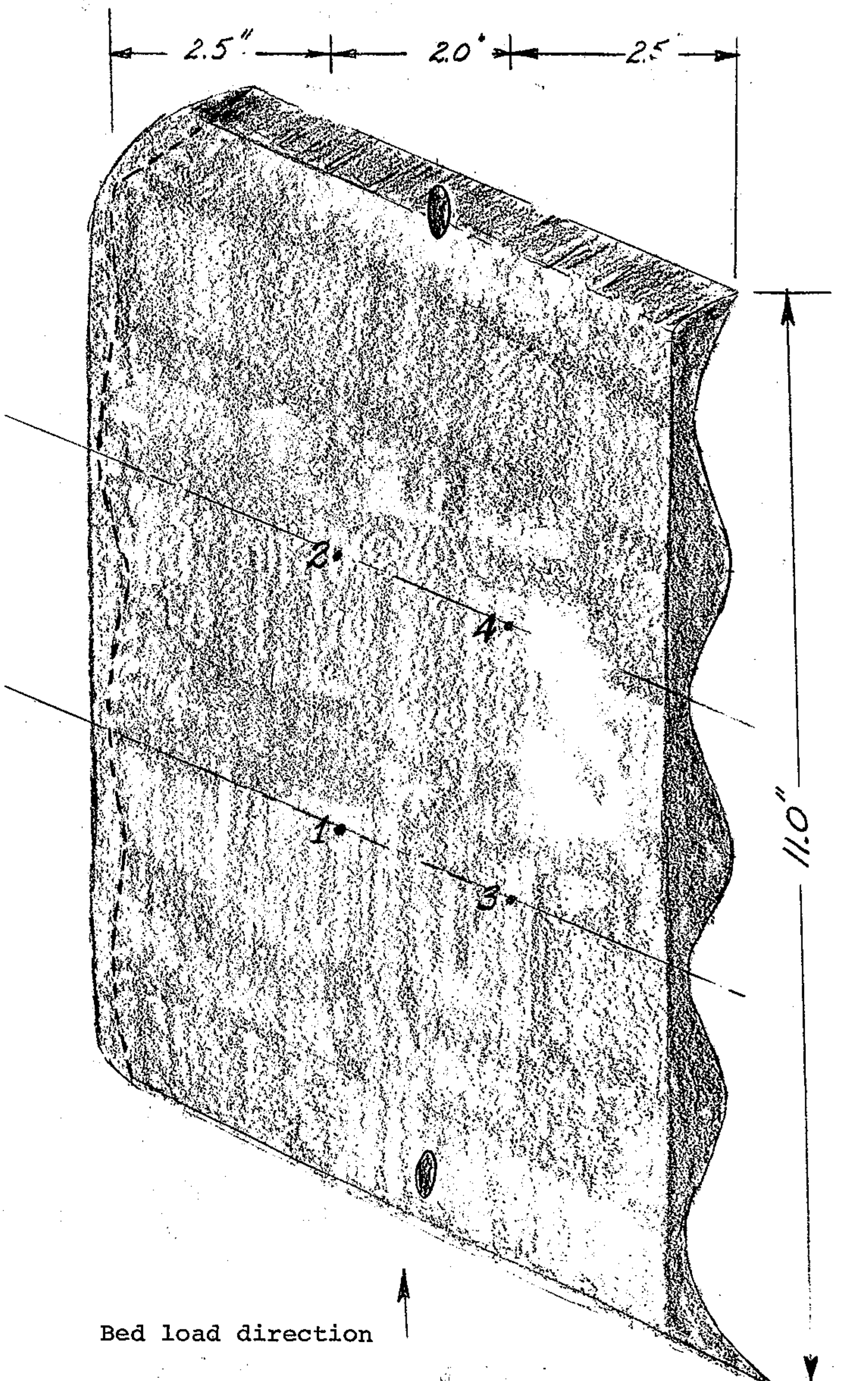


FIGURE 4

Copoly-X Raceway and mortar lined pipe specimen
sizes and thickness measurement locations

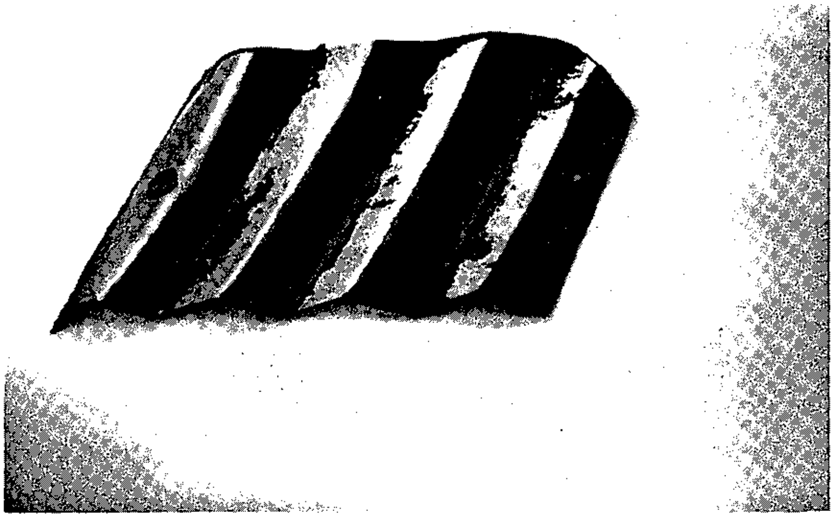


FIGURE 5

INITIAL ABRASION TEST SPECIMEN
Pioneer Culvert Mastic, .025 inch initial coating thickness with 49,022 revolutions at 3.65 fps, 3/8" x 1/2" coarse aggregate abrasive charge.

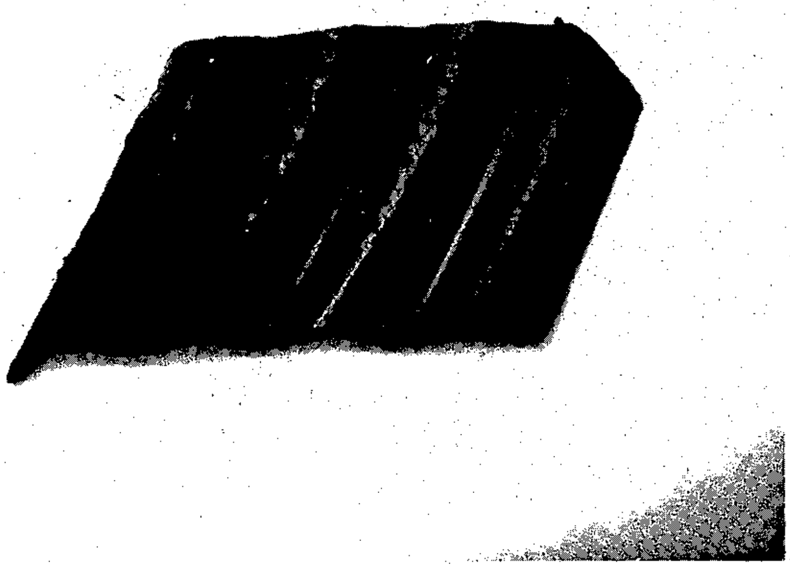


FIGURE 6

INITIAL ABRASION TEST SPECIMEN
Hot-dipped asphalt, .075 inch initial coating thickness with 49,022 revolutions at 3.65 fps, 3/8" x 1/2" coarse aggregate abrasive charge.

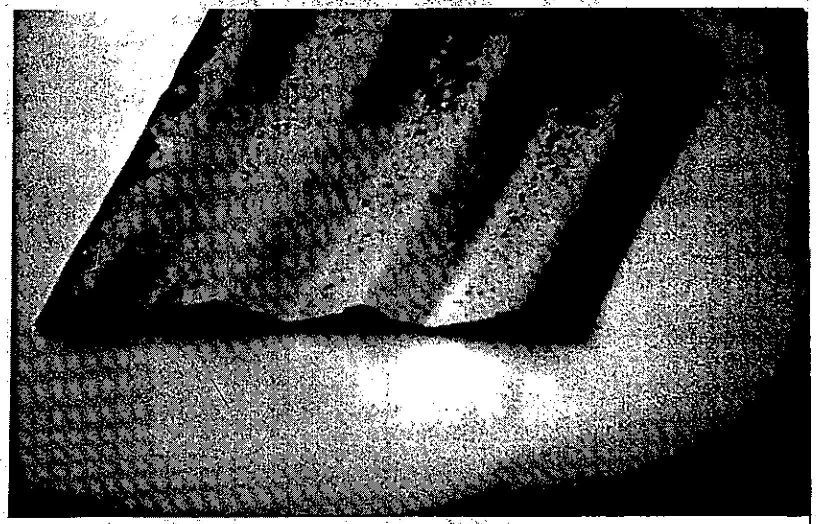


FIGURE 7

INITIAL ABRASION TEST SPECIMEN
Copoly-X Terrashield, .045 inch initial coating thickness with 49,022 revolutions at 3.65 fps, 3/8" x 1/2" coarse aggregate abrasive charge.

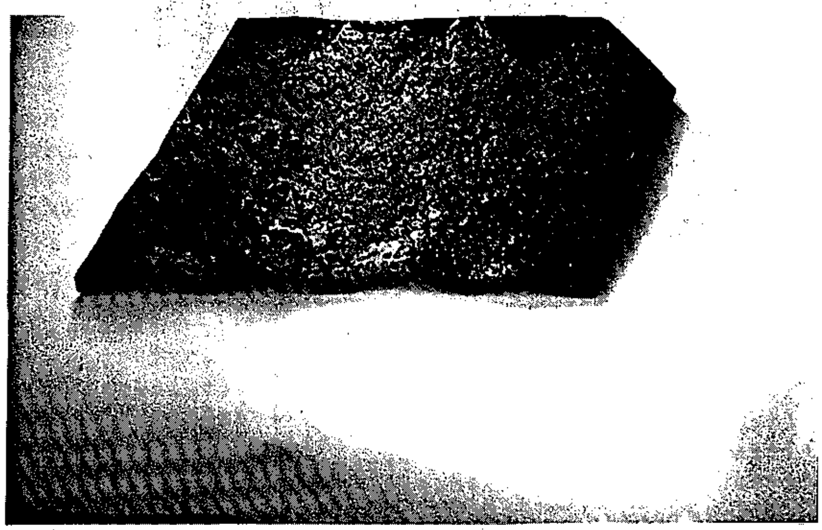


FIGURE 8

New specimen of Copoly-X Raceway

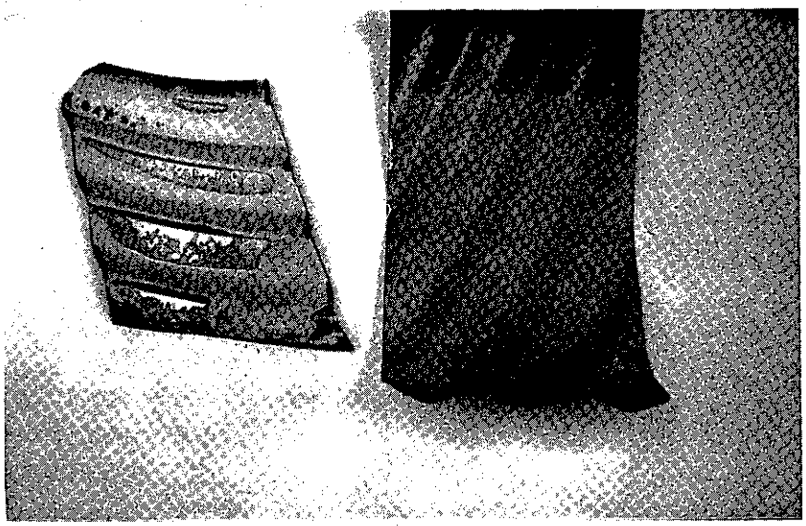


FIGURE 9

Initial abrasion test Copoly-X Terrashield specimen (left) and new Copoly-X Terrashield specimen (right)

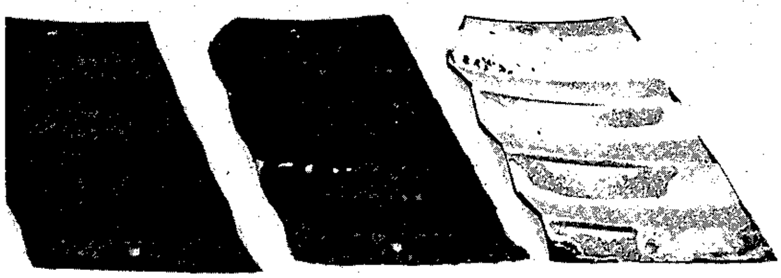


FIGURE 10

INITIAL ABRASION TEST SPECIMENS
.018" Nexon (left), .075" Asphalt (center), and .018" Copoly-X Terrashield (right) all with 174,312 revolutions at 3.65 fps, 3/8" x 1/2" coarse aggregate abrasive charge.

FIGURE 11

ABRASION TEST SPECIMENS
Asphalt (left), Pioneer Culvert Mastic (center) and Nexon (right) with 503,763 revolutions at 5 fps using minus No. 4 fine aggregate as an abrasive charge (see Table 3).

FIGURE 12

ABRASION TEST SPECIMENS
Asphalt (left) and Pioneer Culvert Mastic (right) (see Table 3)

FIGURE 13

ABRASION TEST SPECIMENS
Asphalt (left) and Pioneer Culvert Mastic (center), and Nexon (right) with 501,100 revolutions at 5 fps, using minus No. 4 fine aggregate as an abrasive charge (see Table 4).

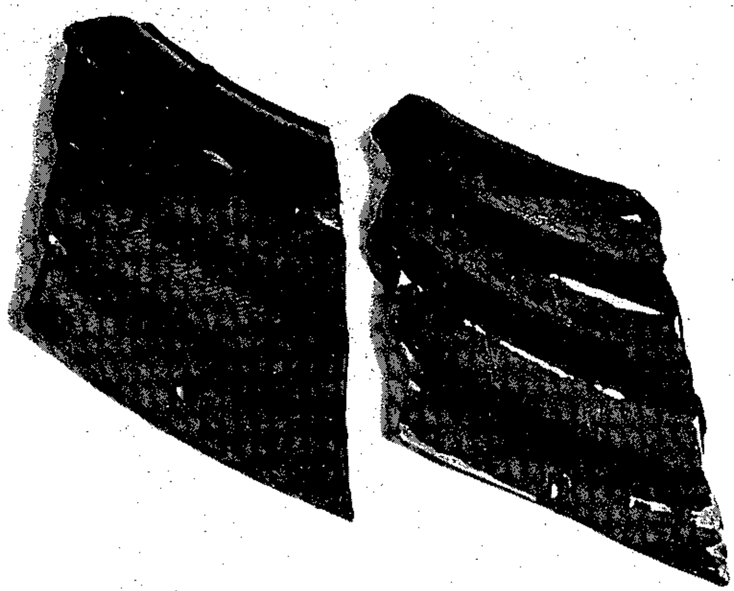


FIGURE 14

ABRASION TEST SPECIMENS
Asphalt (left) and Pioneer Culvert Mastic (right) (see Table 4)

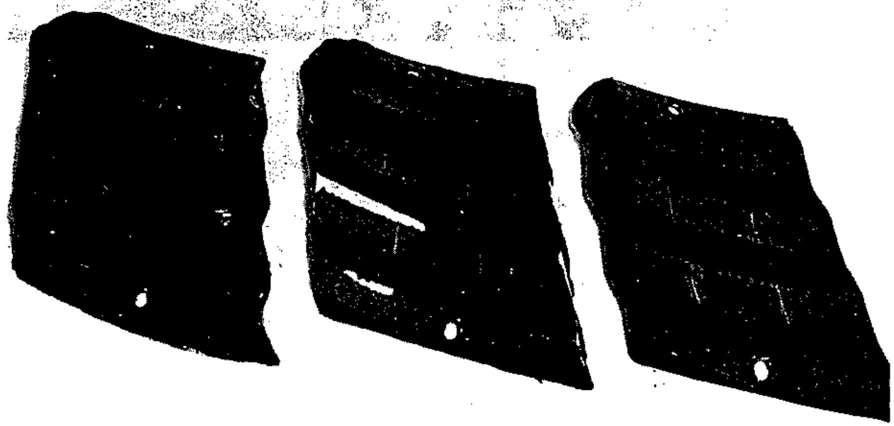


FIGURE 15

ABRASION TEST SPECIMENS
Asphalt (left) and Pioneer Culvert Mastic (center), and Nexon (right), using minus No. 4 fine aggregate as an abrasive charge (see Table 5).

FIGURE 16

ABRASION TEST SPECIMENS
Asphalt (left) and Pioneer Culvert Mastic (right) (see Table 5)

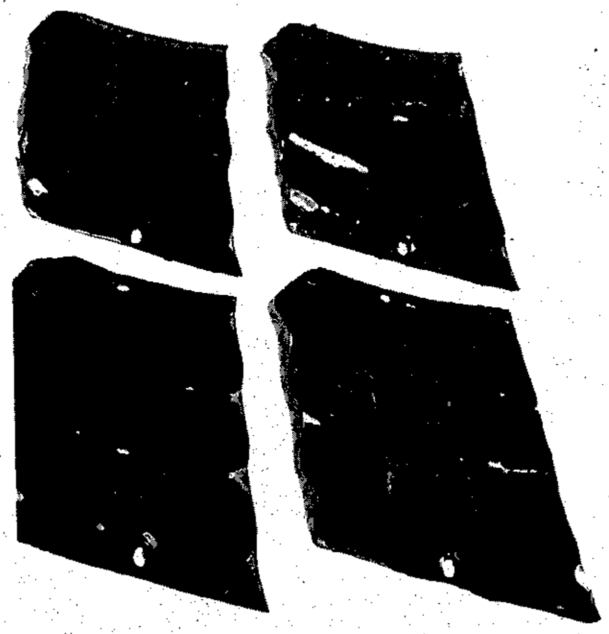


FIGURE 17

Pioneer Culvert Mastic Abrasion Test Specimens with 444,778 revolutions at 5 fps, using minus 4 fine aggregate as an abrasive charge (see Table 6)

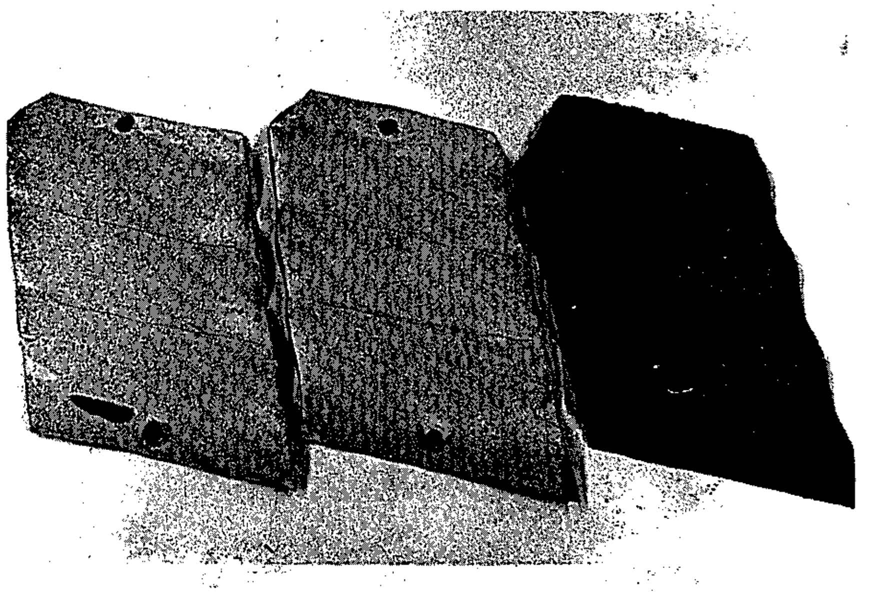


FIGURE 18

Copoly-X Raceway abrasion test specimens, left and center, tested for 121,580 revolutions at 5 fps using 3/8" x 1/2" coarse aggregate as an abrasive charge. Right specimen - new (see Table 7).

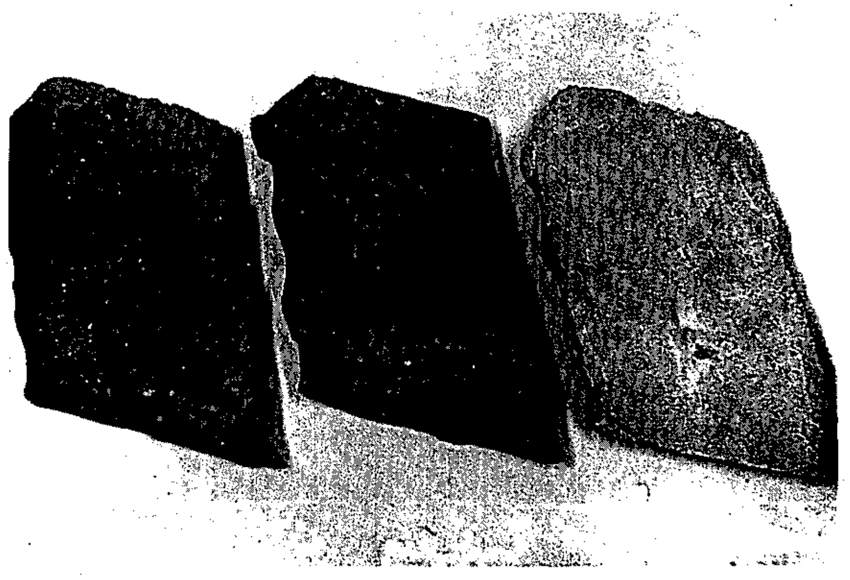


FIGURE 19

Mortar-lined pipe abrasion test specimens, left and center tested for 121,580 revolutions at 5 fps using 3/8" x 1/2" coarse aggregate as an abrasive charge. Right specimen - new (see Table 7).

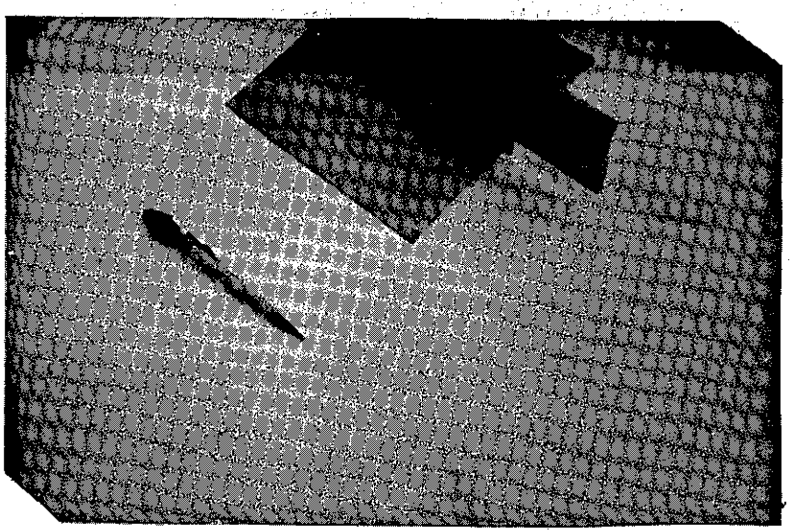


FIGURE 20

Plate bending test apparatus with bent Copoly-X specimen

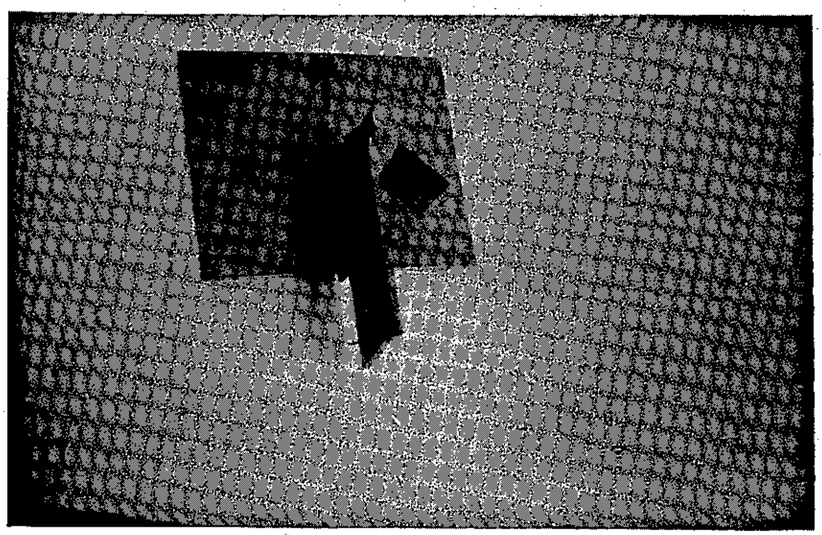


FIGURE 21

Plate bending test apparatus with Nexon specimen

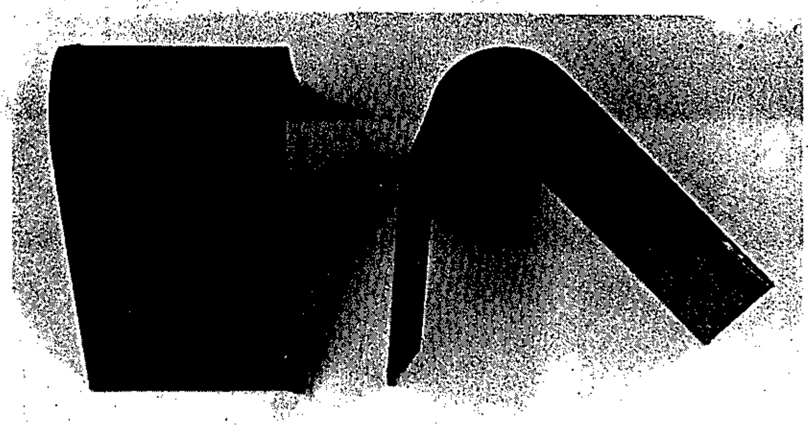


FIGURE 22

Nexon Plate Bending Specimens

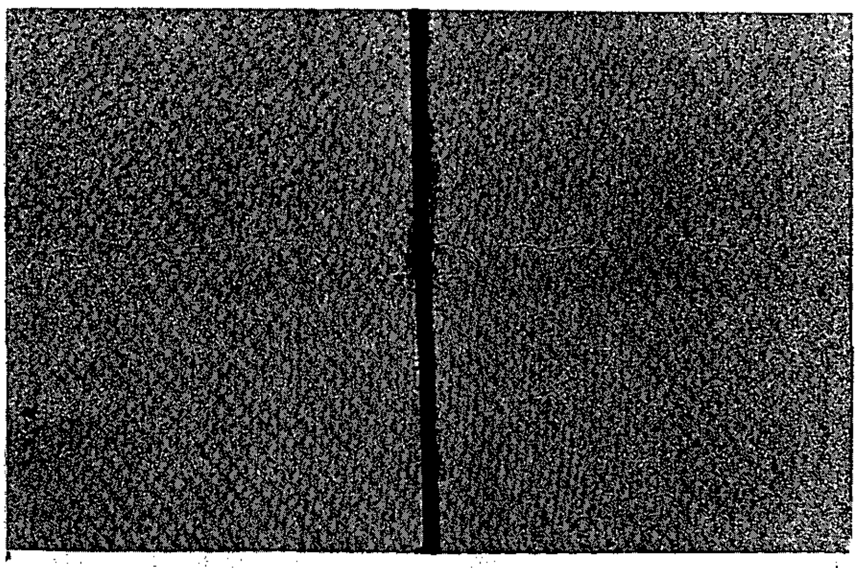


FIGURE 23

Copoly-X Terrashield plate bending specimens having a .018" average coating thickness and bent at angles between 15° and 19° showing small cracks across center of specimens.

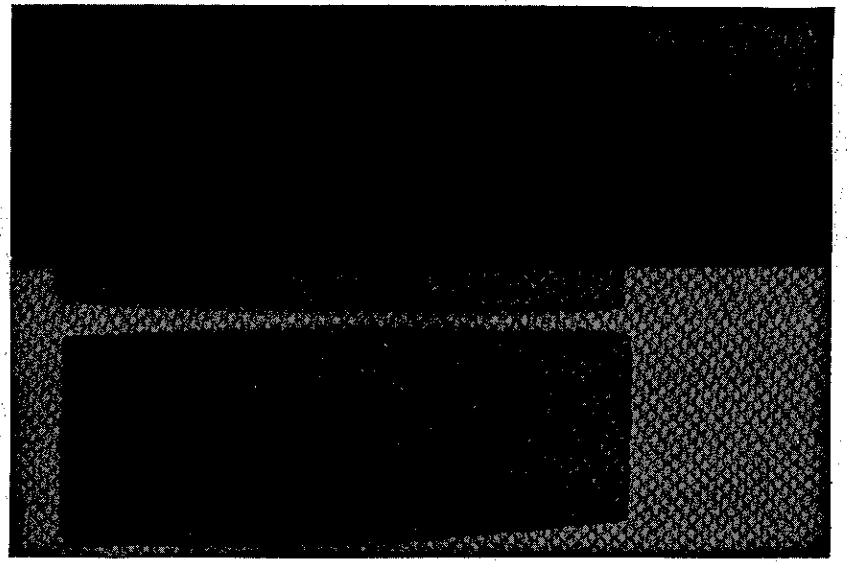


FIGURE 24

Copoly-X Terrashield plate bending specimens, having a .033" average coating thickness and bent at angles between 6° and 9°.

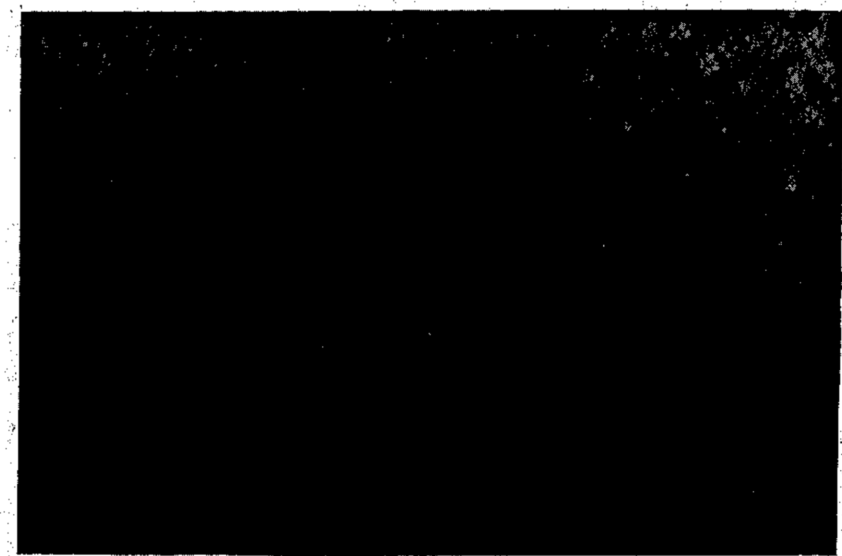


FIGURE 25

Close-up view of Copoly-X Terrashield plate bending specimens in Figure 24 showing large cracks across center of specimens.

FIGURE 26

Ring deflection Copoly-X specimen and Form

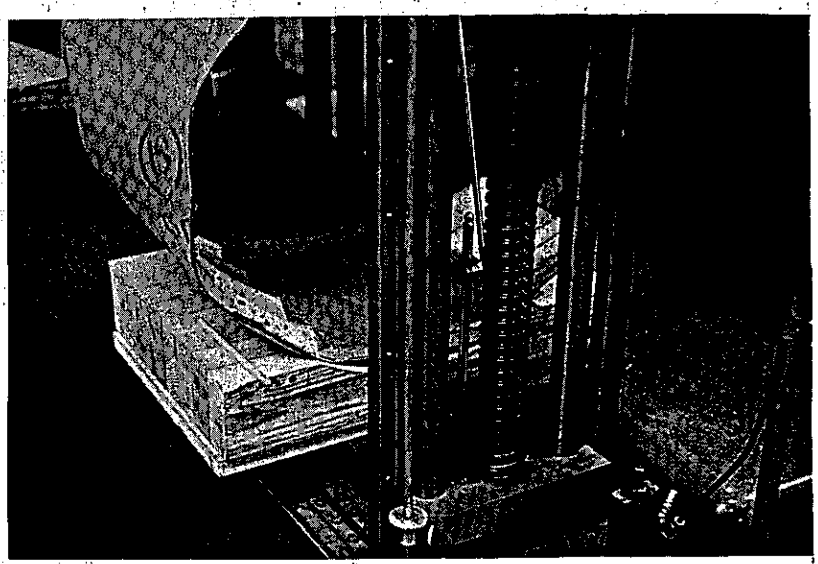


FIGURE 27

View of ring deflection Copoly-X specimen during test

FIGURE 28

View of ring deflection Copoly-X specimen showing crack at Raceway-Terrashield border

FIGURE 29

Close view of crack along Raceway specimen edge at .9 inches deflection during ring deflection test

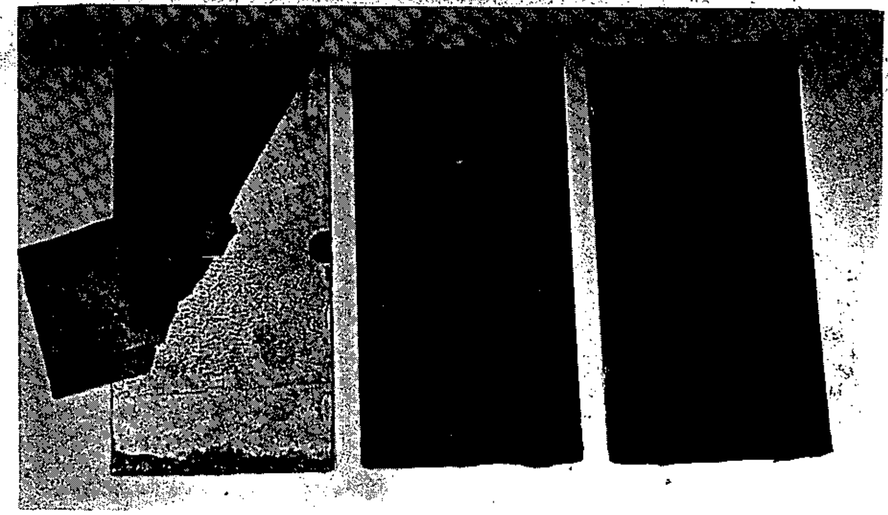


FIGURE 30

Asphalt corrosion test specimens having 4511 hours in the fog chamber

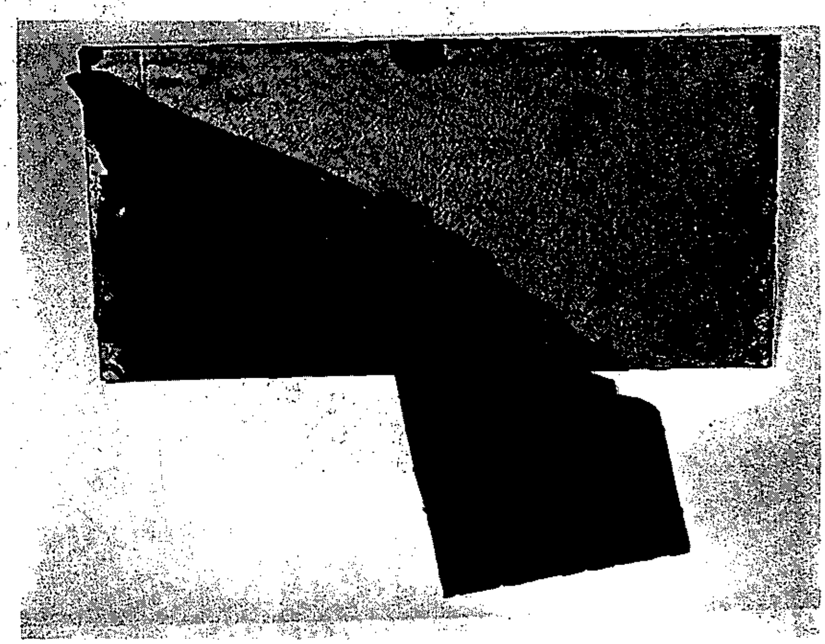


FIGURE 31

Close view of asphalt corrosion test specimen showing loss of bond

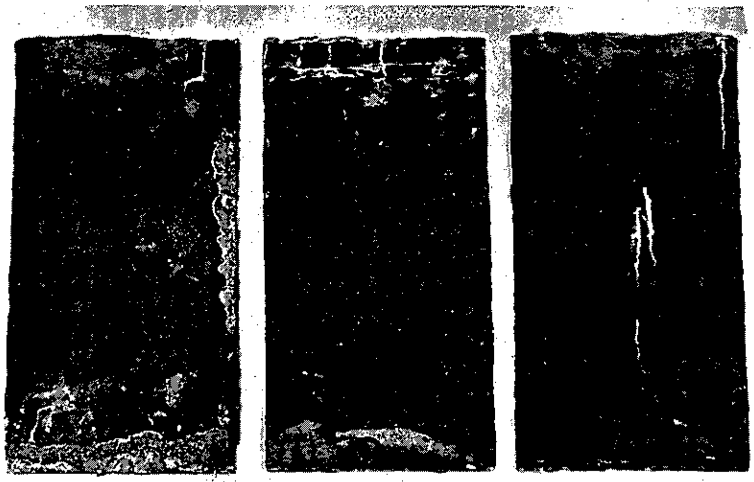


FIGURE 32

Pioneer Culvert Mastic corrosion test specimens having 4511 hours in the fog chamber

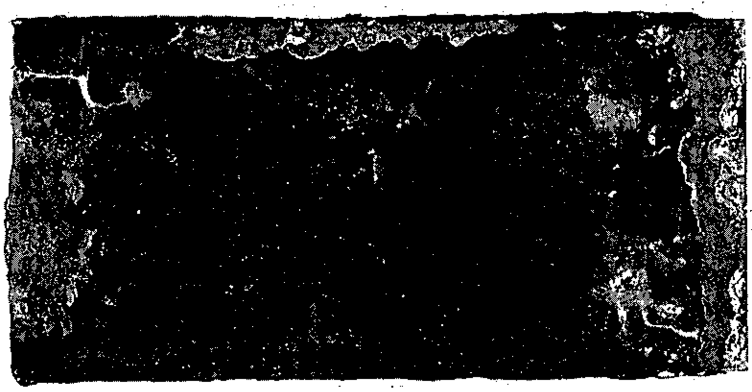


FIGURE 33

Close view of asphalt corrosion test specimen showing extent of underfilm corrosion along edge

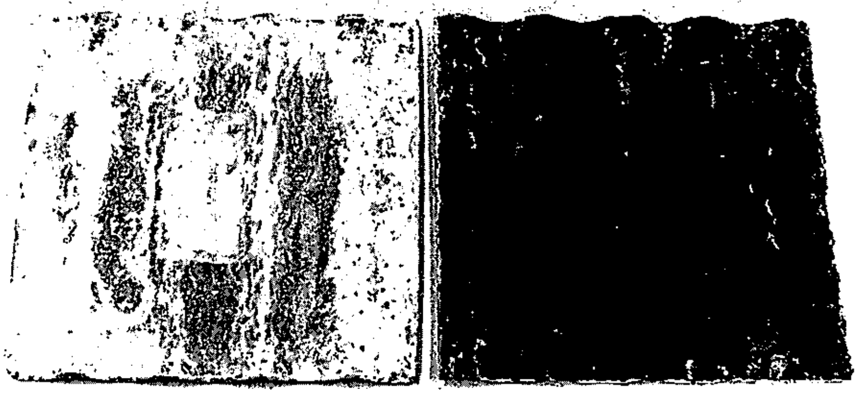


FIGURE 34

Pioneer Culvert Mastic corrosion test specimen having 4511 hours in the fog chamber

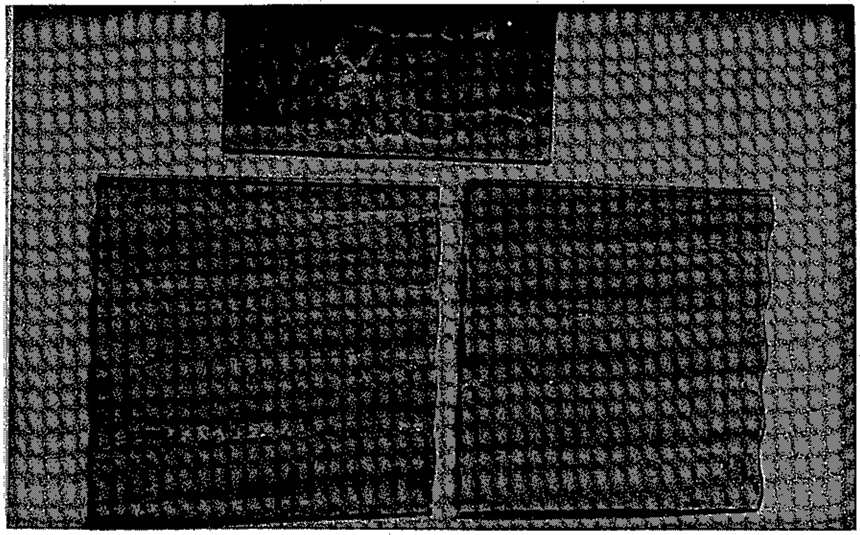


FIGURE 35

Copoly-X Terrashield corrosion test specimens having 4457 hours in the fog chamber

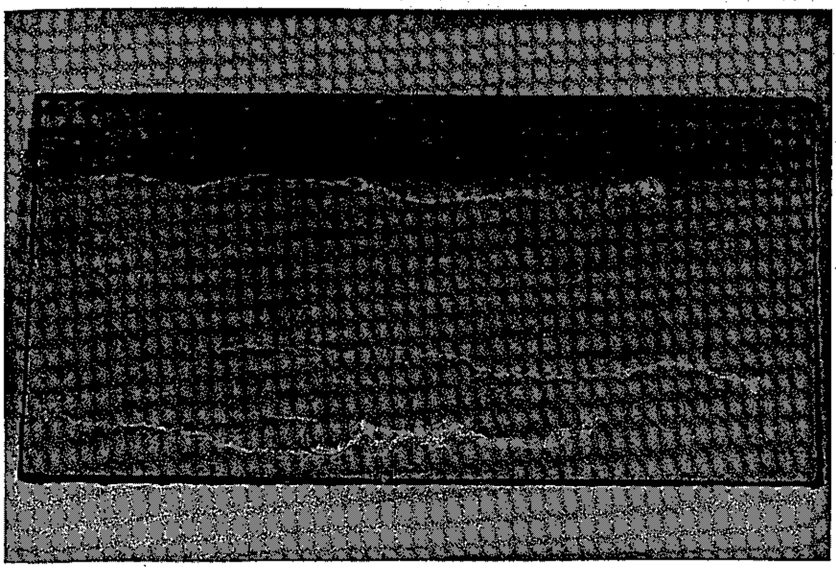


FIGURE 36

Close view of Copoly-X Terrashield specimen showing extent of blisters

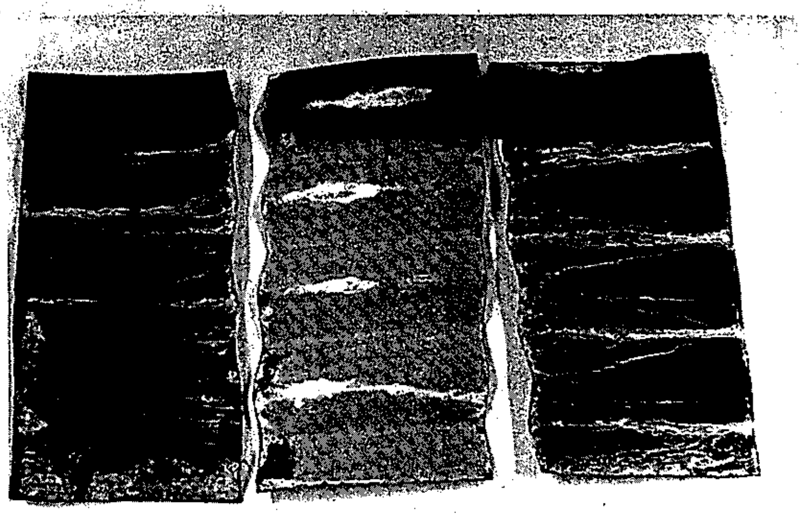


FIGURE 37

Nexon corrosion test specimens having 4511 hours in the fog chamber. Center specimen is turned upside down exposing the yellow epoxy painted surface

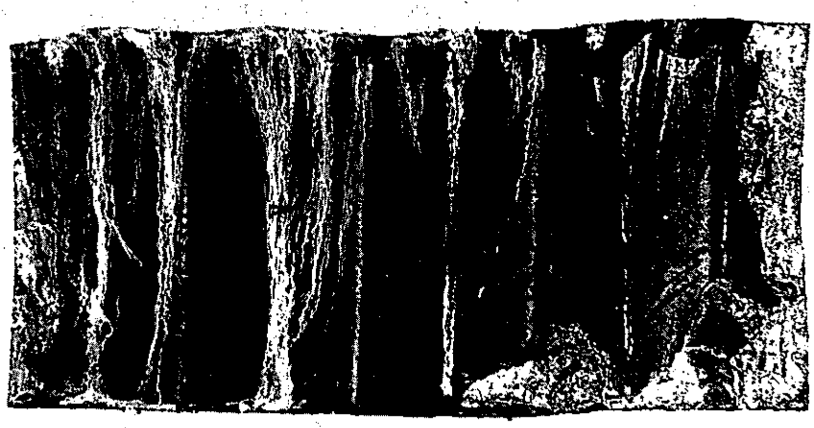


FIGURE 38

Close view of Nexon corrosion specimen showing extent of underfilm corrosion along edge